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# Smart way to finalize Development Drilling Locations by Electrofacies Analysis and validation by Reciprocal Productivity Index Method-Case study from heterogeneous clastic reservoir from Gas field of Tripura

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## Abstract

Electrofacies is defined by similar set of log responses that characterize a specific rock type which is influenced by geology. The process includes data classification and partitioning based on well log response, building of correlation and mapping of reservoir properties using well log followed by application of Reciprocal Productivity Index for result validation. Production, well-log and core data (petrophysical property) of a heterogeneous clastic reservoir in Tripura was analyzed. Principle Component Analysis of the well logs was performed to analyze the data trend followed by cluster analysis to identify the possible Electrofacies. Using available core data correlation between petrophysical property and well-log response was attempted for each electrofacies. Using this correlation petrophysical property map for the reservoir was generated and the same was validated by Reciprocal Productivity Index Method. The map, validated by dynamic data, was used for proposing new development location in the best part of the reservoir.

## Introduction

Prediction of quality of geological facies in terms of its petrophysical parameter is the integral part of the geocellular modelling. The accuracy of the prediction depends on the availability and quality of the data, choice of modelling process and human interpretation techniques. The difficulty level of prediction attains exponential height in absence of geocellular model. This problem is typical in the initial phase of development of a field and especially in the scenario where scarce exploratory well data exists. To cope up with the uncertainty and to generate future development drilling locations multivariate statistical analysis of well logs was adopted as the alternative approach.

Finding similarities among rock type indicators within different well log suits in multivariate log spaces and grouping them into classes is the principle aim of currently adopted multivariate statistical procedure. Different groups generated from this approach are also called electrofacies[1]. Electrofacies symbolize a distinctive set of log responses which portrays properties of the rocks and fluids based on depositional, diagenetic and rock-fluid interrelation characteristics[2]. Serra and Abott were the first to coin the term Electrofacies in 1980 and defined electrofacies as “the set of log responses which characterizes a bed and permits this to be distinguished from others”.

In this paper a threefold approach was considered to achieve the objective. To begin with the log data was classified into various electrofacies by the application of multivariate statistic. Thereafter petrophysical parameters were populated in to each facies and maps were generated. Lastly the maps generated were validated by the dynamic pressure-production data using reciprocal productivity Index method.

## Geological Setting

Present reservoir under study is a subset of Foredeep Super Basin formed due to Eastern part of Himalayan Orogeny. This sub-basin is often termed as Tripura Basin, Assam-Arakan Basin and sometimes even represented by a misnomer “Fold Belt”[3]. The basin is confined from NW side by Vizak-Beijing Paleo Hinge Line and Sylhet Depression. On the Eastern side it gets thrusted over by Himalayan Metapile along Naga Thrust. The hydrocarbon bearing fields of Tripura are part of Assam- Arakan basin. The reservoir facies is mainly heterogeneous sandstone and non-reservoir facies is shale. The lower limit of pools is generally represented by aquifer as being a part of gas-water system. Major orientation axis of the plays is N-S (Arakan Trend), which is further articulated by ENE- WSW and NNW-SSE trends. Towards East of the producing fields, Naga thrust is still active and heading towards West (Figure 1). Seismic studies exhibit that in the Bhuban section there is multiple scouring, scooping out and re-depositional phenomenon of sediments is quite common. All the reservoirs explored till date reveal that the entrapment of gas has been strongly influenced by structural vectors. However the deltaic architecture of shifting channels, scooping and re-deposition etc. present a challenging, chaotic geological picture to deal with in modelling as well as in managing reservoirs in conventional way[4].

## Methodology

In the present study we have considered well log suite from 4 wells (TRGI-6, 9, 15 and 35) having GR, SP, ILD, DT, NPHI and RHOB along with depth track. Selected intervals of pay sand TRXP-1 were screened out from the log suites on the basis of already identified seismo-geological markers. We have undertaken Principle Component Analysis on the recorded log suites in 4 wells from pay sand TRXP-1 in a producing field in Tripura, followed by K-Means cluster analysis to identify and distinguish different electrofacies. Using available core data, an empirical relationship was developed between the well log responses and petrophysical properties for each of the electrofacies group. The information obtained was translated spatially over the whole field using suitable interpolation technique. The generated map using static data was subjected to validation by the parameters deduced from dynamic data i.e. pressure-production data. Application of Reciprocal Productivity Index (RPI), using prolonged pressure-production data provided realistic flow capacity/damage value within the drainage boundary of the well which in turn was used to validate the electrofacies properties map. This map is used to flag-mark and optimize the proposal of development drilling locations.

## Electrofacies Identification

The method of electrofacies identification is based on identification of clusters of well log responses with similar characteristics. This is a two step procedure as discussed below.

**Step 1: Principle Component Analysis-** Principle Component Analysis (PCA) is a tool for the identification of patterns in the data. PCA summarizes the data effectively with the reduction of dimensionality without loss of information. In order to minimize the effect of scale and environmental effect, all the log suite read data was normalized by subtracting each value of recorded log suite from its corresponding mean and dividing by standard deviation[5]. For the normalization of depth track each depth value was first transformed from Measured Depth KB to Mean Sea level (MSL) and then subtracting each observation value for shallowest occurrence of the pay sand under consideration and dividing by the same. This is termed as Structural Consideration. PCA was carried out on the normalized data to determine the principle components. Figure 2 depicts the Scree plot, showing variance of principle components. It is evident that only 4 principle components explain 93.36% of variation in the whole data set. The correlation profile of major two components is presented in Figure 3. The Eigen vector of the covariance matrix is presented in the Table 1. The major two components being

$$\boldsymbol{PC1} = 0.001\,\textbf{\textit{Structural Consideration}} + 0.508\,\boldsymbol{SP} - 0.448\,\boldsymbol{RHOB} + 0.573\,\boldsymbol{NPHI} - 0.325\,\boldsymbol{ILD} + 0.328\,\boldsymbol{GR}$$

$$\boldsymbol{PC2} = 0.002\,\textbf{\textit{Structural Consideration}} + 0.222\,\boldsymbol{SP} - 0.097\,\boldsymbol{RHOB} - 0.206\,\boldsymbol{NPHI} - 0.729\,\boldsymbol{ILD} + 0.606\,\boldsymbol{GR}$$

**Step 2: Cluster Analysis-** Cluster analysis is performed with the target to classify the data set in to groups in such a way that objects within the same group are internally similar to each other and externally desolated from the other groups in terms of measurement of similarity. In the present study, K-Means clustering technique was undertaken to identify the distinct groups based on the well log measurement. K-Means clustering algorithm is one of the most popular algorithm[6] and it works without any priori information[7]. 5 different distinct groups of cluster were identified taking observation of first 4 major components determined from PCA. Each cluster treated as electrofacies, represents unique hydrological, lithological, depositional and diagenetic characteristics. Figure 4 shows the well wise relative positioning of clusters in the principle component space. Figure 5 shows the relative position of electrofacies perforated in each well in principle component space.

## Determination of Petrophysical Parameters

All available core analysis data was arranged in a well wise manner. Data with no depth tag was discarded. As good reservoir facies yields poor recovery, Vshale curve, derived from log suite and core analysis, was used for fine-tuning of depth signatures of the samples. Using differentiated data of core derived k and $\phi$, Flow unit model was prepared. Flow unit model thus prepared, exhibited a smooth high slope cloud suggesting that change in rock fabric is gradual and smooth and denotes the presence of one flow unit only. This is contrary to flow behavior of wells and classical problem in ERD technique[8]. Thus, input data and ERD parameters derived were arranged in well- wise, layer- wise manner. Total data set was fragmented and tagged in layer wise populations. Flow Unit model was rebuilt and FZI values were determined. As a second step, multiple regressions were carried out between the depth matched core data and values of all log tracks available at the depth of respective core sample. Thus modified FZI equation was formed and was used for permeability determination for the Lowell log suite[4]. The equations are stated below.

$$FZI\rho_B = 2.1591\rho_B + 5.4697$$

$$FZINPHI = 0.0315(100*NPHI) - 0.3082$$

$$\mathbf{RMSFZI} = \sqrt{\frac{FZI\rho B^2 + FZINPHI^2}{2}}$$

$$\mathbf{K} = 1937.8(\mathbf{RMSFZI})^{2.652}$$

Using these above equations permeability values of all five electrofacies were calculated well wise and placed inTable-2.

## Discussion

PCA and Cluster analysis of the log suites of wells TRGI-6, 9, 15 and 35 reveal that the pay sand TRXP-1 consists of at least 5 different electrofacies. Co-variance matrix generated from PCA depicts that variable structural consideration plays insignificant role on the electrofacies. This indicates that Structural deformation is post depositional and not syn-depositional phenomenon as otherwise a reverse picture should have emerged. Electrofacies 1 shows a higher affinity towards NPHI, GR and SP and relatively lower affinity to resistivity. This may be attributed to mineralogical composition of rock forming grains and the effect of clays in the formation. Higher GR and SP values may be indicative of shaly sandstone. Electrofacies 2 exhibits moderate influence of NPHI, RHOB & ILD and lower GR and SP values. Increase of RHOB, GR and SP value is observed in electrofacies 3. Electrofacies 4 is having high RHOB and ILD but low NPHI count. This may be attributed to the abundance of heavy minerals in the rock forming grains. Lower GR and SP value may be indicative of clean sand but lower salinity value of connate water in relation to other electrofacies. Electrofacies 5 shows highest GR and SP count. This may be indicative of tight shaly part of the reservoir. Figure 4 shows schematic reservoir quality in the principle component space. Figure 5 also exhibits that dominant perforated electrofacies in well TRGI-6 and TRGI-35 is 2, in TRGI-15 is 4 and in TRGI-9 is 2, 3 and 4. To demonstrate distribution of the all the electrofacies in spatially, Fence Diagram was prepared passing through wells TRGI- 35, 15, 6 and 9 (Figure-6).

Performance history of all the 4 wells (Figure-7) reveals that TRGI-6 is the best performer followed by TRGI-35 which is having a relatively short history. TRGI-15 did not perform well for the pay sand TRXP-1 and well TRGI-9 only showed gas indication during testing. Enhance Reservoir Description (ERD) reveals maximum permeability in electrofacies 2 and minimum permeability in electrofacies 5. These values were used for making permeability templates as the permeability trends generated form ERD may replicate the trend in the reservoir. Therefore integrating all the information i.e. performance history of the wells, ERD study and multivariate statistical analysis it was concluded that electrofacies 2 is the most promising flow-facies in pay sand TRXP-1. This also indicates that relatively poor performance of TRGI-15 can be attributed to non-development of electrofacies 2 the well. In TRGI-9 though electrofacies 2 is present but during testing only electrofacies 1 was perforated due to its location in deeper structural level and closer to Gas Water Contact. On the basis of this integrated study, one development location was finalized targeting electrofacies 2, 4, 3 in order of choice and the location is proposed suitably between wells TRGI-6 and TRGI-9 (Figure-6).

## Validation

Validation of the above inference was done using the Reciprocal Productivity Index (RPI) analysis. RPI is defined as the opposite of the productivity index and has great importance in classic reservoir engineering calculations. The methodology provides a direct way to measure average reservoir pressure, permeability and skin directly from the pressure production data of the well[9]. Theoretically RPI is expressed as

$$I(t) = \Psi_i \frac{1}{q_s} - \frac{S}{P_{DC}}$$

ψi= Pseudo potential
qs= Surface Gas Rate
S= Skin
PDC= 2πkh/ρ
k=Permeability
H=Thickness
ρ= Gas Density

Plot of I(t) vs $\psi_i(1/q_s)$ yields skin as the y intercept and average flow capacity can be determined from RPIMDH plot. The slope of RPI MDH plot provides the flow capacity of the region around the well. Plot of RPIMDH of well TRGI-6 yields average permeability value of 71.22 md which is slightly less than the permeability determined from ERD. For well TRGI-35 the permeability determined was 65.81 md (Figure-8). Both the permeability in accordance with the permeability determined from ERD. This may be corroborated as the validation of the process developed for the finalization of the future development drilling location.

## Conclusion

Electrofacies analysis provides good insight of the reservoir during the initial development stages where the well data is scarce and geological model is absent. Caution should be taken for the PCA as non normalized data could lead to erroneous result.

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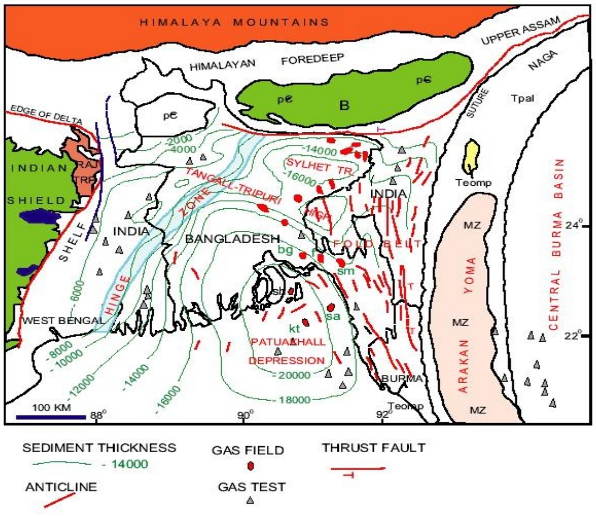

**Figure 1**: Regional Geological map of Tripura-Bangladesh Sub-Basin, (After USAID- U.S. Dept. of Energy, released for public domain PASA No. 388-P-99-0002C)

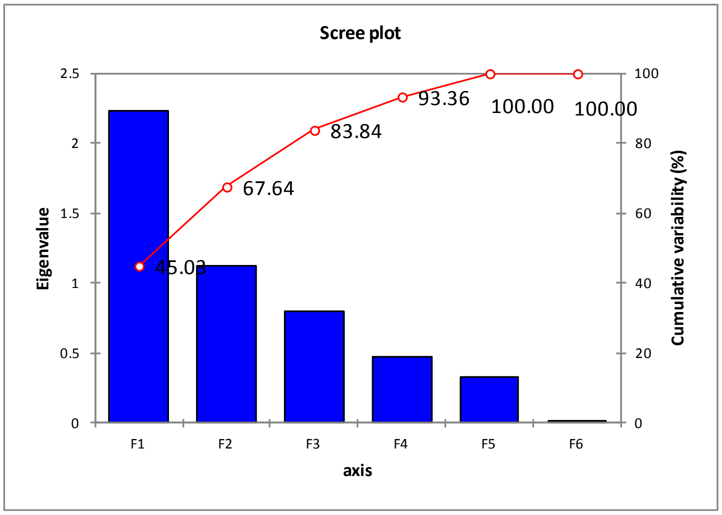

**Figure 2**: Scree Plot showing variance of principle components

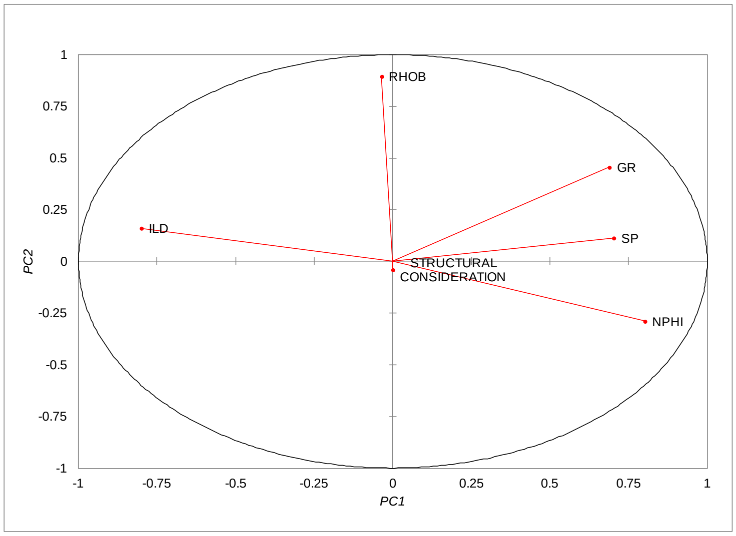

**Figure 3**: Correlation profile of major two components

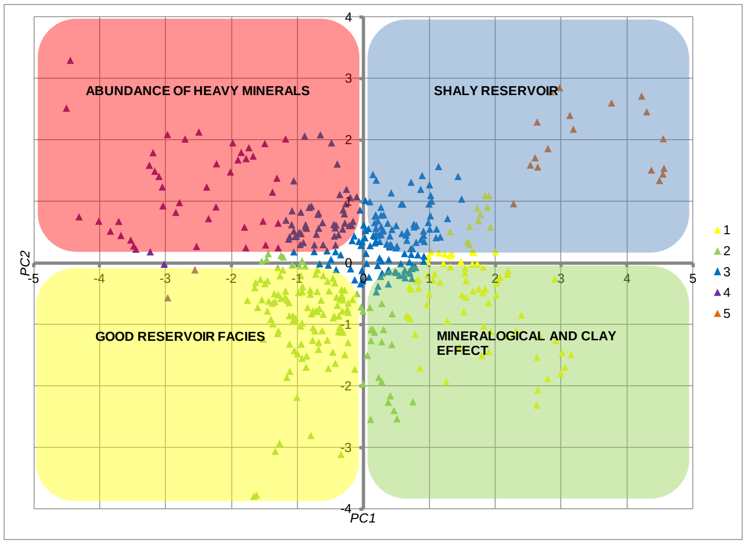

**Figure 4**: Relative position of clusters in the principle component space

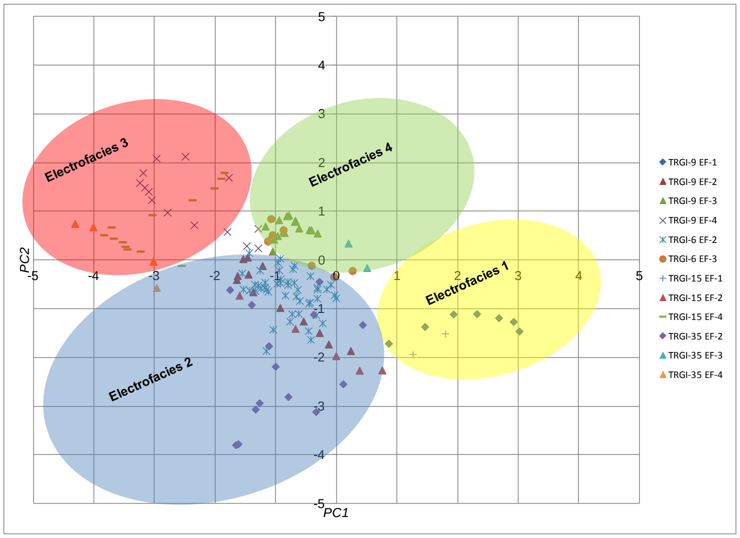

**Figure 5**: Relative position of electrofacies perforated in each well in principle component space

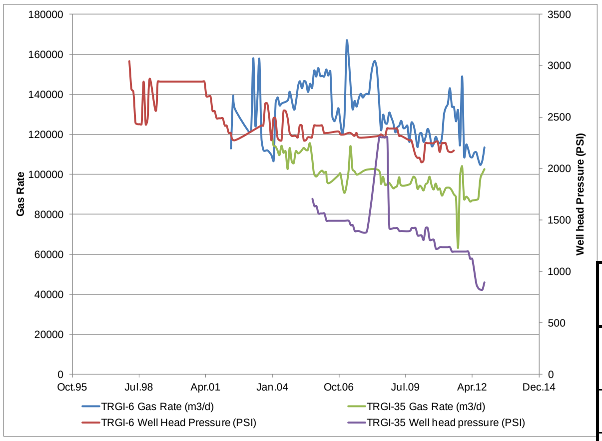

**Figure 7**: Performance History of well TRGI-6 and 35

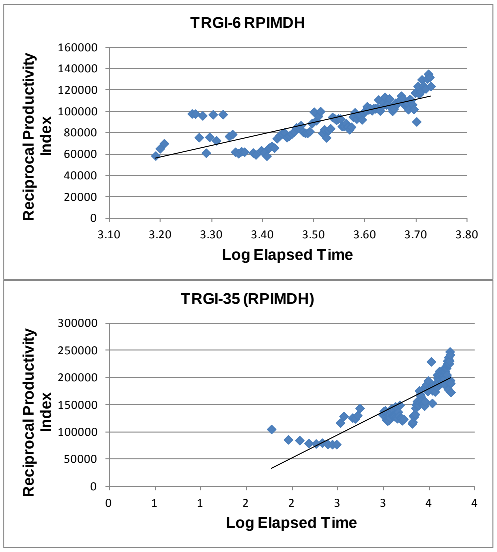

**Figure 8**: RPIMDH plot of well TRGI-6, 35

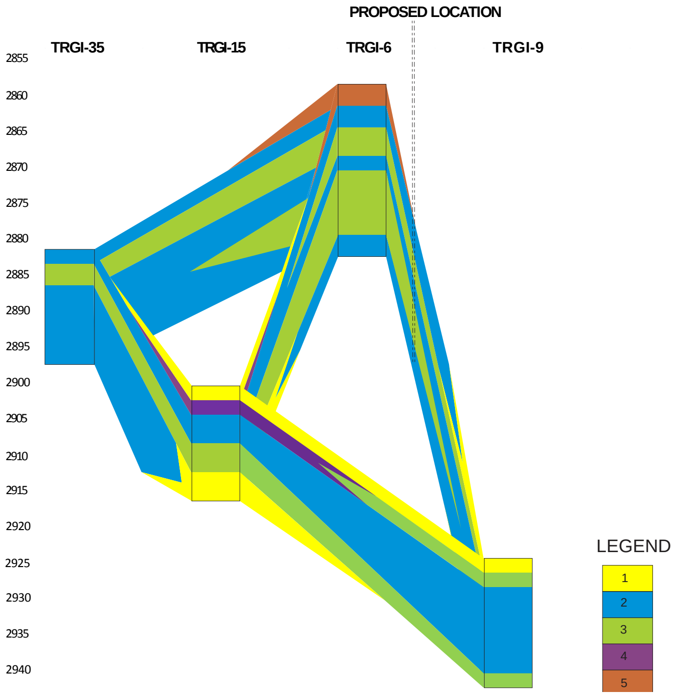

**Figure 6**: Fence Diagram showing spatial distribution of all electrofacies

| Component Variable | PC1 | PC2 | PC3 | PC4 | PC5 | PC6 |
|---|---|---|---|---|---|---|
| **Structural Consideration** | 0.001 | 0.002 | 0.000 | 0.000 | 0.000 | 1.000 |
| **SP** | 0.508 | 0.222 | -0.084 | 0.813 | -0.159 | -0.001 |
| **RHOB** | -0.448 | -0.097 | 0.745 | 0.428 | 0.228 | 0.000 |
| **NPHI** | 0.573 | -0.206 | 0.161 | -0.135 | 0.765 | 0.000 |
| **RILD** | -0.325 | 0.729 | -0.301 | 0.074 | 0.517 | -0.001 |
| **GR** | 0.328 | 0.606 | 0.567 | -0.364 | -0.266 | -0.001 |

**Table 1**: Co-variance matrix generated from PCA

| **Well** | **Permeability (md) of the electrofacies** | | | | |
|---|---|---|---|---|---|
| | **1** | **2** | **3** | **4** | **5** |
| TRGI-6 | 31.07 | 93.67 | 27.72 | 51.94 | 13.21 |
| TRGI-9 | 15.43 | 47.77 | 14.52 | 28.85 | ND |
| TRGI-15 | 29.70 | 69.89 | 16.78 | 53.41 | ND |
| TRGI-35 | 29.48 | 74.43 | 24.67 | 55.40 | ND |

*ND- Not Developed

**Table 2**: Permeability values of each electrofacies determined well wise.